Effect of Trap Color and Orientation on the Capture of *Aphelinus mali* (Hymenoptera: Aphelinidae), a Parasitoid of Woolly Apple Aphid (Hemiptera: Aphididae)

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ABSTRACT   The factors affecting trap capture of adult *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) were studied in 2010–2011 in eastern Washington apple (*Malus* spp.) orchards infested with its host woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Hemiptera: Aphididae). The initial study of white sticky cards indicated that traps stapled to the trunk in a vertical orientation had the highest capture. A factorial experiment of three colors (clear, white, and yellow) by three orientations (trunk, scaffold, and hanging) indicated that yellow traps and traps on trunks caught higher numbers of *A. mali*. For this reason, the recommended trap for this natural enemy is a yellow trap stapled to the trunk. Having a readily available and effective sampling method for this species may be helpful in implementing biological control programs and assessing the impact of different spray regimes.

KEY WORDS   *Aphelinus mali*, trap, color, orientation

Aphelinus mali (Haldeman) (Hymenoptera: Aphelinidae) is an endoparasitoid of woolly apple aphid, *Eriosoma laningerum* (Hausmann) (Hemiptera: Aphididae), that was first discovered in eastern North America, the same region of origin as its host. In the early 1920s, its potential role in biological control of a significant apple (*Malus* spp.) pest was noted, and a concerted plan for rearing and distribution was implemented (Howard 1929). The distribution of *A. mali* worldwide is among the outstanding early examples of classical biological control. Immediately after introduction, most areas reported establishment and spread, and many reported satisfactory biological control (Howard 1929).

Decades after introduction, the performance of *A. mali* was reassessed in several areas (DeBach 1962, Bonnemaison 1965). Although some areas still reported satisfactory results (especially in warmer growing regions), there were a growing number of regions where woolly apple aphid was still a significant pest, despite the action of the parasitoid (Massee 1943, Evenhuis 1958). Several reasons have been cited: poor synchrony with the host in spring, lower reproductive rate, fewer generations than the host; higher developmental temperature threshold than the host; and competition with predators, and susceptibility to pesticides (Bonnemaison 1965).

However, *A. mali* remains an established component of the natural enemy complex attacking woolly apple aphid and virtually the only parasitoid of importance (Asante 1997). In New Zealand, where there is a dearth of generalist aphidophagous predators, *A. mali* is carefully conserved as the primary biological control agent (Wearing et al. 2010). As long as disruptive pesticides are omitted, *A. mali* exerts economic biological control in these circumstances. Recent evidence from eastern Washington (Gontijo and E.H.B., unpublished) also reaffirms that *A. mali* plays a role in overall biological control of woolly apple aphid.

The occurrence of *A. mali* was studied recently in eastern Washington both indirectly (as percentage parasitism of the host) and directly (adults captured in sticky bands) (L. Gontijo et al. unpublished). Although sticky bands (used primarily to sample migrating crawlers) did capture *A. mali* adults, the method is too laborious and inefficient to be used commercially. Sampling *A. mali* when its host levels are low (percentage of parasitism) is problematic, and may not represent the potential impact of the parasitoid. To better understand its seasonal abundance, I compared several methods of trapping *A. mali* adults by using sticky cards.

Materials and Methods

Trapping was conducted during two growing seasons (2010–2011) in four apple orchards in Douglas County, WA. All orchards were chosen for having a

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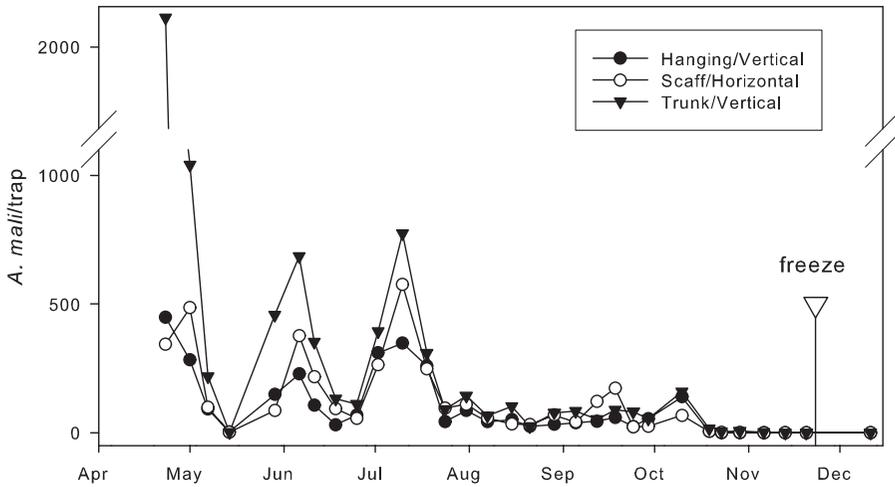
Fig. 1.   Seasonal abundance of *A. mali* on white sticky traps of three different orientations, ST1, 2010.

history of woolly apple aphid infestation and presence of *A. mali.*

In 2010, traps were placed in a single apple orchard, ST1, a minimally sprayed research orchard with a high density of woolly apple aphids. The orchard was planted in 1990, and consisted of 'Fuji' with 'Gala' pollenizers. Three trap orientations were tested: 1) stapled to the tree trunk (vertical orientation), 2) stapled to a scaffold limb (horizontal orientation), and 3) suspended from a limb. All traps were a white rectangular sticky card (9 by 15 cm; San Jose scale card, AlphaScents, West Linn, OR) and were placed ≈1–1.5 m above the ground. The traps were double-sided, but the release paper was left in place on one of the surfaces, so that only one sticky surface was exposed. For traps attached to the trunk or scaffold, the sticky surface faced out, and for the hanging trap, the sticky surface faced the tree trunk. There were three replicate blocks (randomized complete block design), with treatments (trap orientations) spaced ≈3.7 m apart. Traps were deployed in mid-April and collected and replaced weekly until mid-December. The number of *A. mali* on the entire trap surface was counted and recorded.

Based on the 2010 results, the experiment was expanded in 2011. Two additional sites were chosen, one site ≈21 km north (CLY) and the other ≈34 km south (CRO) of the original site. Both of these sites were commercial orchards, the former organic and the latter conventional. In addition to the three orientations, three colors (white, yellow, and clear) were tested in a 3 by 3 factorial arrangement. The clear trap was assumed to represent passive capture of insects moving about the orchard.

In the early part of the season, mid-April to mid-June, traps were custom fabricated to include a clear trap with the same adhesive as the other traps. White and yellow card stock was cut to the same size as the commercial San Jose scale trap (9 by 15 cm) and coated with a spray adhesive (Tangle Trap Sticky Coating, The Tanglefoot Co., Grand Rapids, MI). The

clear trap was constructed from a piece of clear rigid acrylic cut to the same size as the San Jose scale trap, with a piece of 9-mil plastic film coated with the adhesive attached to the surface. The trap position was similar in most respects to the 2010 experiment, except that both sides of the hanging traps had exposed sticky surfaces. The resulting count was halved to correspond to the same surface area as the single-sided traps. In addition to the 3 by 3 factorial design, a 10th treatment was added (the commercial white San Jose scale trap, stapled to the trunk) to provide a comparison of adhesives.

The data from the early season made it apparent that the adhesive used on the commercial trap was superior in terms of *A. mali* capture, and the experiment was restarted in mid-June with traps using only this adhesive. A clear trap was identified (WindowBugCatcher, AlphaScents), which along with a yellow sticky card from the same manufacturer (cut to the 9- by 15-cm size), made it possible to use the more effective adhesive for all three traps. The white and yellow cards were double-sided, and the same method described for 2010 was used to make them single-sided when attached to the trunk or scaffold. The same piece of rigid acrylic was used as a support for the clear traps. The WindowBugCatcher was attached using the provided 1.5-cm sticky strip plus double-sided tape to ensure that it remained flat on the surface of the acrylic backing. Clear traps were affixed to both surfaces of the acrylic supports. The two surfaces of the hanging traps were counted and recorded separately, making the design a three (color) × four (orientation) factorial. One side of the hanging traps faced the tree trunk, and the other side faced the row middle.

The woolly apple aphid populations were sampled weekly each time the traps were collected and changed. Relative densities were estimated by recording the number of aphid colonies found during a 1-min search of each replicate. Replicates were averaged to provide a single value for that orchard.
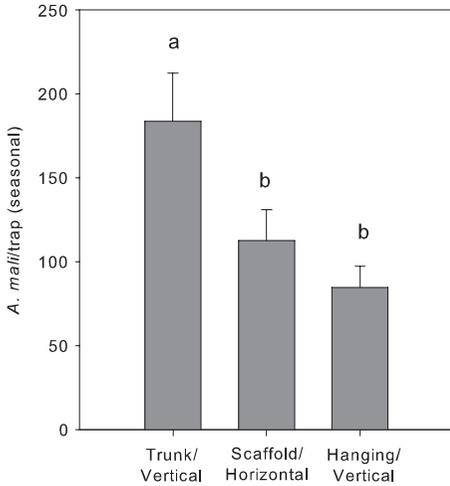
Fig. 2. Average trap capture of *A. mali* on white sticky cards in three orientations, April–December 2010.

There were five (CLY, CRO) or four replicates (ST1) for each treatment, with each replicate contained in a single row. The replicates were spaced two to six rows (9–30 m) apart, and treatments within rows were spaced 3–11 trees (6–21 m) apart, depending on block size and tree spacing. Traps were rotated each week to the next trap location in the row, so that each treatment occupied multiple positions throughout the season. Traps were deployed in mid-June and counted and changed weekly through early December.

Although the primary objective was to determine an optimum trapping method for *A. mali*, a secondary objective of these experiments was to look at the patterns of seasonal abundance of *A. mali*, and the variation among orchards. The paired trap captures and woolly apple aphid density estimates were used to examine synchrony between host and parasitoid.

Data Analysis. The mean seasonal trap capture was used to compare trap color, type, or orientation. The 2010 data were analyzed as a randomized complete block design. The early and late tests in 2011 were analyzed as a 3 by 3 or 3 by 4 factorial, respectively. All analyses were carried out using PROC GLM (SAS Institute 1988), with the Waller–Duncan k-ratio *t*-test mean separation procedure.

Results and Discussion

2010. Peak captures occurred on the first collection date, with >2,000 adults per trap on 21 April in one of the treatments; presumably first emergence was a week or two earlier. The initial peak in late April (during bloom) was followed by two more peaks, one peak in early-mid June and a second peak in early-mid July (Fig. 1). Trap captures remained relatively low for the rest of season, and no *A. mali* were captured after mid-November. A severe freeze from 23 to 25 November, with minimum temperatures in the −15 to −20°C range, made further captures unlikely.

The vertical/trunk trap caught the highest numbers of adults quite consistently throughout the season (Fig. 1), and the seasonal mean capture was statistically higher than the other two trap types (Fig. 2). Traps suspended from a limb caught the lowest numbers overall, with the scaffold/horizontal orientation intermediate, although the latter two types did not differ statistically. These findings support the observed behavior of aphelinids of preferentially searching for prey on the tree trunks by walking or hopping, rather than flying (Viggiani 1984).

2011, Early Season. Relative trap catches of *A. mali* were low in the CLY orchard, moderate at CRO and high at ST1 (Figs. 3 and 4). The AlphaScents trap caught significantly more *A. mali* at all sites during this
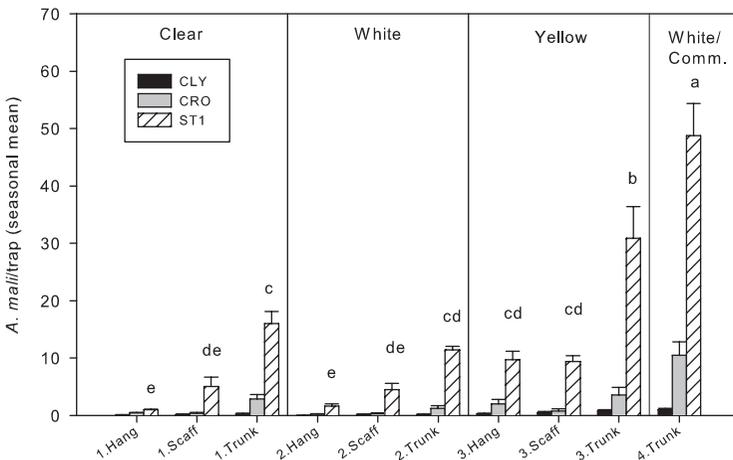

Fig. 3. Seasonal mean capture of *A. mali* on traps of three colors (clear, white, and yellow) and three orientations (trunk, scaffold, and hanging), plus a white commercial San Jose scale trap stapled to the trunk, April–June 2011. Bars that do not have the same letter above them differ significantly using the Waller–Duncan mean separation test for data from the STI orchard with a significant interaction term (see Table 1).
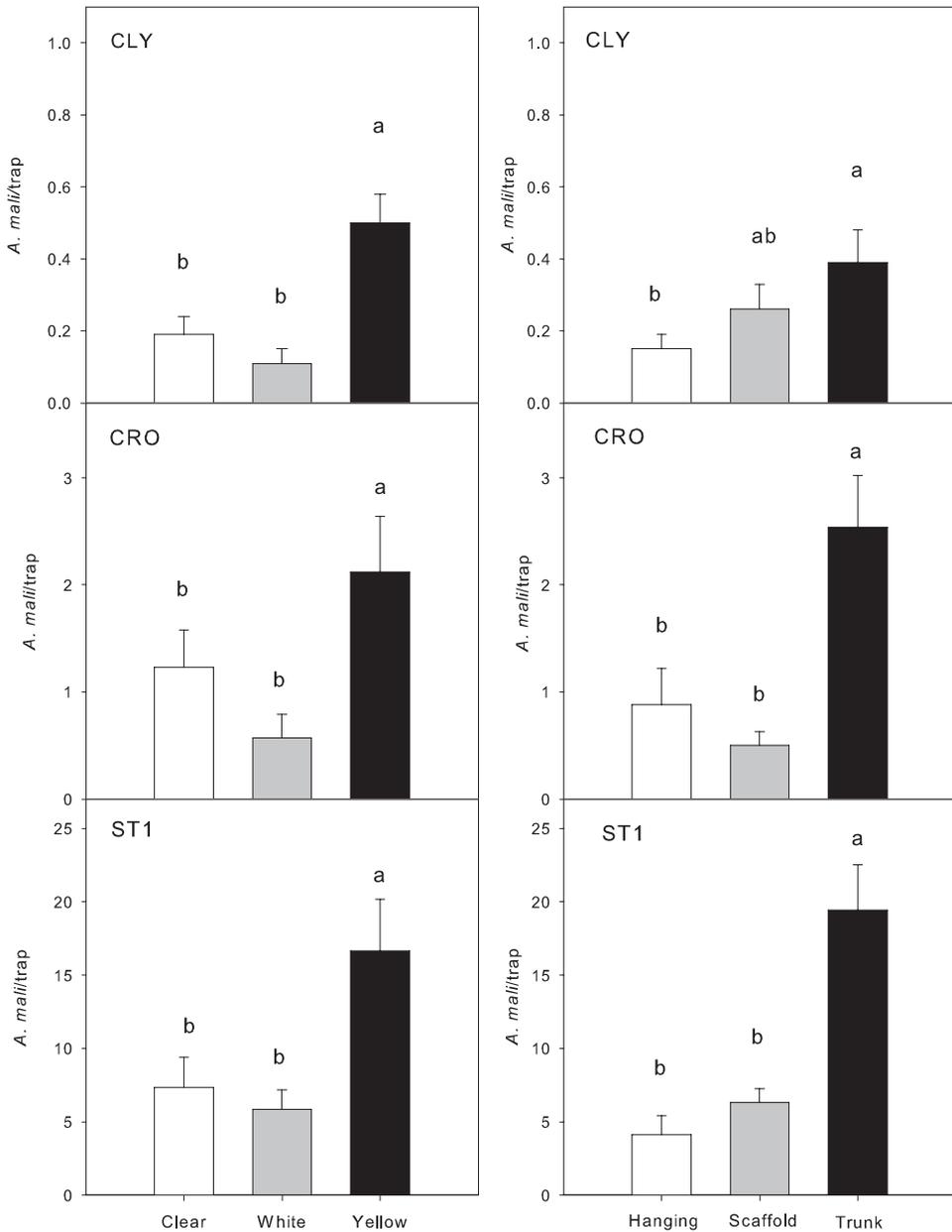
Fig. 4. Average captures of *A. mali* on sticky traps of different colors and orientations in three orchards (CLY, CRO, and ST1) in eastern Washington, April–June 2011. Factor-level means of trap color (left) and trap orientation (right).

period than the comparable trap (Tanglefoot adhesive, white, stapled to trunk) (CLY: $F = 6.26$; df = 1, 4; $P = 0.05$; CRO: $F = 158.94$; df = 1, 4; $P = 0.0002$; and ST1: $F = 54.85$; df = 1, 3; $P = 0.005$) (Fig. 3), and this was the major motivation to change to traps using the AlphaScents adhesive exclusively.

Despite the inefficiency of the adhesive on the custom-fabricated traps, there was a clear difference in *A. mali* trap catch for the main effects color and orientation (when the commercial trap was excluded from the analysis). Yellow was significantly more attractive to *A. mali* (Fig. 4) than clear or white traps at all three sites. The trap stapled to the trunk caught significantly more *A. mali* than traps stapled to the scaffold or hanging in the CRO and ST1 sites; the scaffold trap was intermediate at CLY, although numbers during the early season were very low at this site. The *F*-values for the factors color and orientation were highly significant at all sites, and with the exception of ST1, the interaction term was not significant (Table 1). Of the Tanglefoot traps, yellow traps stapled to the trunk caught the highest numbers of *A. mali*, and the clear and white hanging traps the lowest numbers.

Table 1. *F-statistics for a 3 by 3 factorial treatment arrangement of* A. mali *trap captures in three eastern Washington orchards, April–June 2011*

Source	CLY		CRO		ST1	
	df	F, P	df	F, P	df	F, P
Color	2	14.32, <0.001	2	6.23, 0.005	2	22.41, <0.001
Orientation	2	5.38, 0.009	2	12.30, <0.001	2	40.85, <0.001
Color × orientation	4	1.30, 0.289	4	1.14, 0.355	4	3.09, 0.033

The df values in the table are for factors; error df = 36.

2011, Late Season. Traps in the minimally sprayed research orchard (ST1) caught the highest numbers of *A. mali* during this period, with similar (lower) levels in the two commercial orchards (Figs. 5 and 6). The higher capture on yellow cards was noted at all three sites, whereas mean captures on clear and white traps were not statistically different. The traps attached to the trunk (CRO) or trunk and scaffold (CLY, ST1) caught significantly higher numbers of *A. mali* relative to hanging traps (Fig. 6). The hanging traps had the lowest captures, with no statistical differences between the sides facing the trunk versus the row middle. The results of the factorial analysis were similar to the early season results: *F* values for the factors color and orientation were highly significant at all sites, and with the exception of CRO, the interaction term was not significant (Table 2).

There was no clear evidence of discrete generations of *A. mali*, and no consistent pattern of association with its woolly apple aphid host in the three orchards (Fig. 7). In the CRO and ST1 blocks, there was an initial peak in trap captures during and after bloom, because of overwintering mummies at this site; however, early season activity was at very low levels at the CLY site. The aphid population at CLY was at elevated levels from mid-June through late August, with no fall peak. *A. mali* densities were

relatively low until mid-August, and peaked several weeks after the host populations. There were two fairly distinct peaks of woolly apple aphid activity at the CRO site, one peak in midsummer and one peak in fall. After the initial emergence, *A. mali* densities were moderate through the summer aphid activity, peaked in mid-August and probably contributed to the decline in aphid populations. Densities of *A. mali* rose again with aphid populations in September through early October but declined to near zero by mid-October. At the ST1 site, woolly apple aphids were present at low-to-moderate levels from May through December, with no distinct peaks, but with generally higher levels from mid-August onward. After the initial spring emergence of *A. mali*, populations fluctuated throughout the season, but declined to near zero by early October.

Three generalizations can be drawn from these data. First, a peak emergence of *A. mali* during bloom is dependent on a large overwintering population of mummies, which is in turn dependent on a large fall population of the host. This was clearly lacking at the CLY site, and given that this orchard is under organic management, it is unlikely that a highly toxic material was sprayed prebloom that would have killed emerging *A. mali*. Second, lack of host aphids may be the reason for the decline of *A. mali* populations after emergence; this is one of the reasons cited by Bonnemaison (1965) for insufficient biological control. Population recovery of *A. mali* may take many weeks, and a rapid response to rising host aphid populations was not always evident. However, the juxtaposition of the two peaks may indicate that *A. mali* eventually contributes to the suppression of host populations. Lastly, *A. mali* ceases to be active by early to mid-October, entering diapause as larvae inside the mummified host. Woolly apple aphids can continue to increase in density well into the fall and early winter, in the
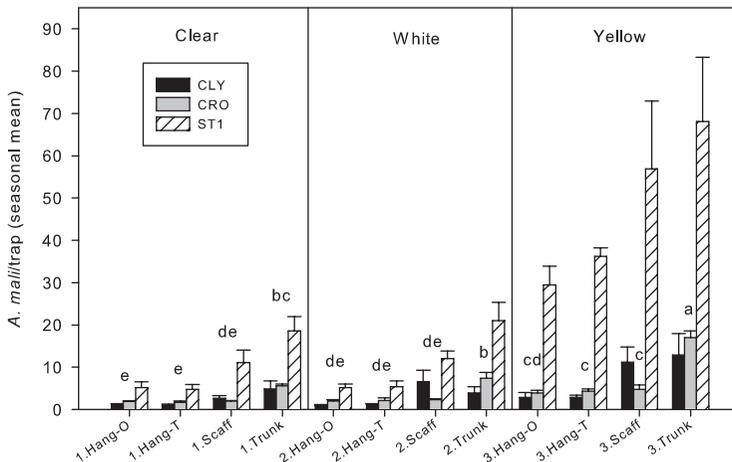

Fig. 5. Seasonal mean capture of *A. mali* on traps of three colors (clear, white, and yellow) and four orientations (trunk, scaffold, hanging/facing trunk, and hanging facing row middle), June–December 2011. Bars that do not have the same letter above them differ significantly using the Waller–Duncan mean separation test for data from the CRO orchard with a significant interaction term (see Table 1).
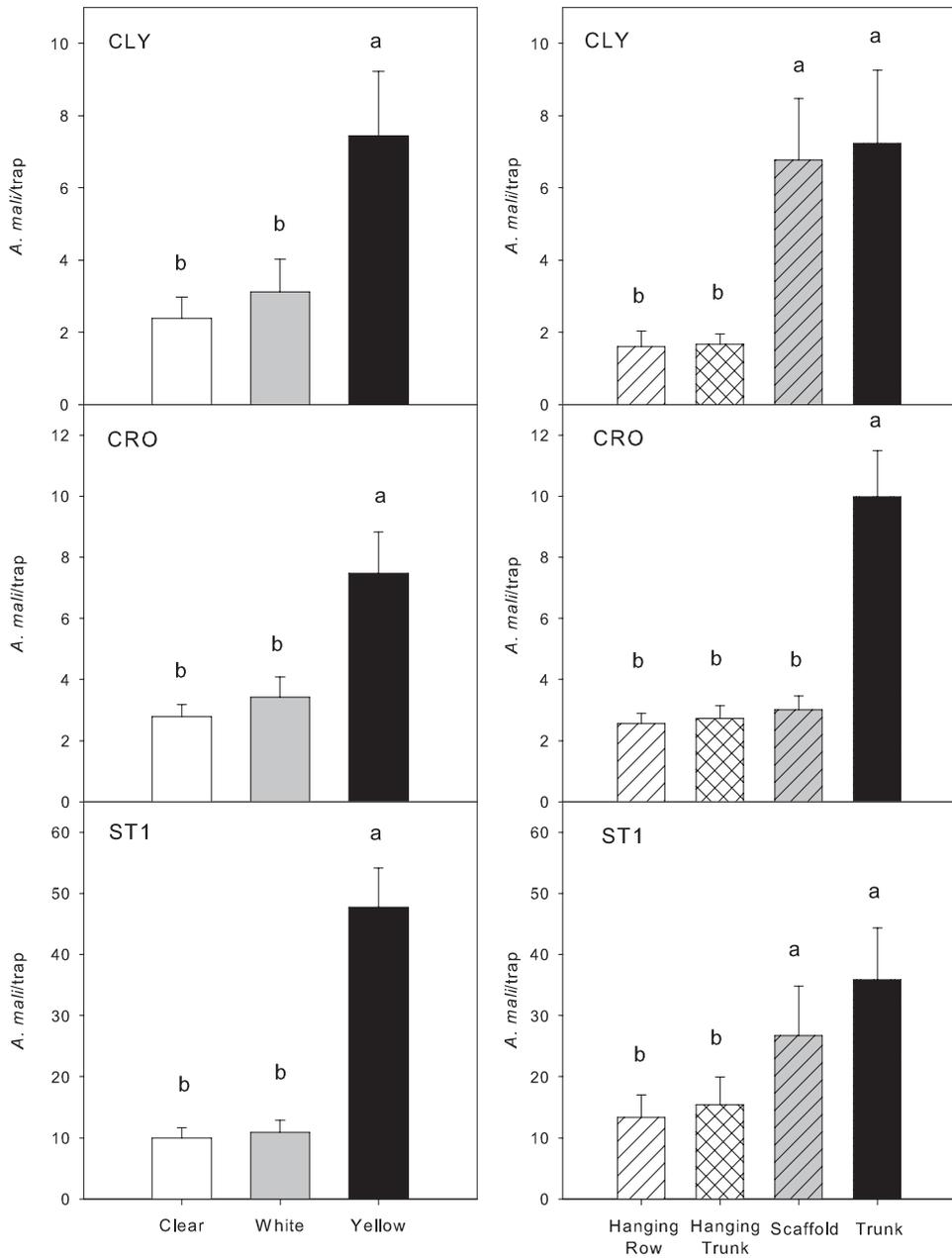
Fig. 6. Average captures of *A. mali* on sticky traps of different colors and orientations in three orchards (CLY, CRO, and ST1) in eastern Washington, June–December 2011. Factor-level means of trap color (left) and trap orientation (right).

Table 2. *F*-statistics for a 3 by 4 factorial treatment arrangement of *A. mali* trap captures in three eastern Washington orchards, June–December 2011

Source	CLY		CRO		ST1	
	df	*F, P*	df	*F, P*	df	*F, P*
Color	2	6.67, 0.003	2	42.39, <0.001	2	39.84, <0.001
Orientation	3	6.47, 0.001	3	64.24, <0.001	3	7.11, 0.001
Color × orientation	6	1.14, 0.355	6	9.49, <0.001	6	0.94, 0.476

The df values in the table are for factors; error df = 48.

absence of parasitism. However, factors other than *A. mali* may be influencing aphid densities, including pesticides and predators, thus the host–parasitoid relationship shows only a part of the picture.

Although any of the traps tested could be used to monitor *A. mali* activity, a yellow card attached to the trunk would provide the most sensitive indicator at low populations. The greater problem lies in determining what, if any, predictive value the traps have. At the least, they can be used to determine seasonal abundance of a parasitoid that would be
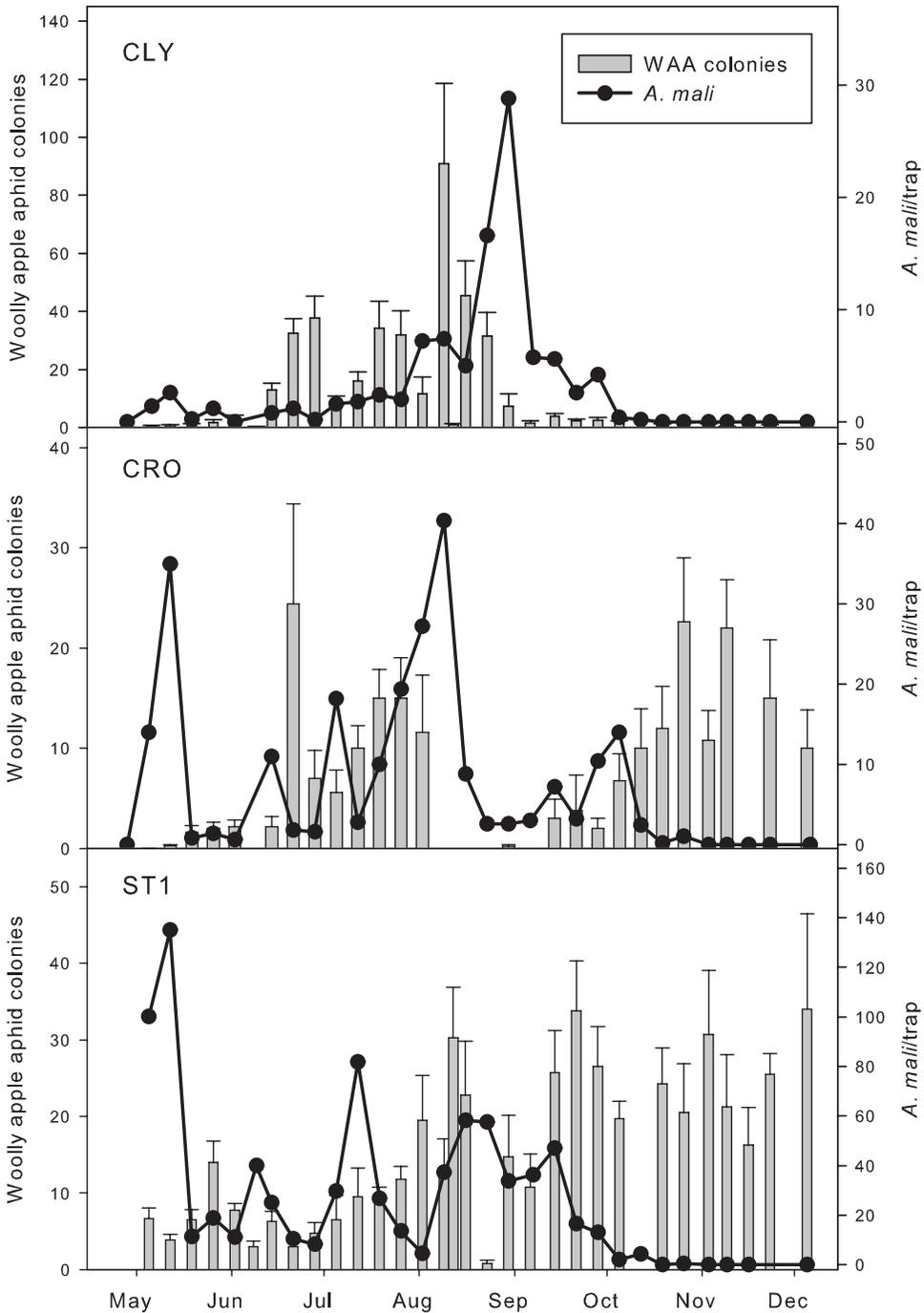
Fig. 7. Seasonal captures of *A. mali* on white sticky cards stapled to the trunk compared with the population density of its host, woolly apple aphid (as determined by 1-min colony counts), May–December 2011.

laborious to sample by visual inspection of aphid colonies (as in Pringle and Heunis 2008). Colony sampling, although yielding an estimate of percentage parasitism, is difficult to do when aphid populations are extremely low. Having an independent measure of both host and parasitoid is helpful in this regard, especially if one (the trap) is a cumulative measure over time as opposed to a single point in time sample. Traps are much less labor intensive than colony sampling, and require no equipment other than a hand lens. They also may provide an overall measure of the selectivity of a spray program (toxicity to *A. mali*), at least where the host is not being rigorously controlled.

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